USAARL Report No. 2013-13

Injuries to Occupants of U.S. Army High Mobility Multipurpose Wheeled Vehicles in Rollover Accidents, 1989-2007

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United States Army Aeromedical Research Laboratory

Warfighter Protection Division

April 2013

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
2-4-2013	Final	1989-2007

4. TITLE AND SUBTITLE

Injuries to Occupants of U.S. Army High Mobility Multipurpose Wheeled Vehicles in Rollover Accidents, 1989-2007

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Michael Lo, Robert Giffin, Kraig Pakulski, Paul St. Onge, Joe McEntire, Shean Phelps, Amy Barrett, Dan Wise, Parrish Balcena

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362-0577

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL 2013-13

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Materiel Command
504 Scott Street
Fort Detrick, MD 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

USAMRMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This study analyzed reported occupant restraint use among U.S. Army Soldiers who were injured in High Mobility Multipurpose Wheeled Vehicle (HMMWV) rollover accidents reported to the U.S. Army Combat Readiness / Safety Center. During the time period studied (1989 through 2007), Soldiers who reportedly had not worn occupant restraints were three times more likely to die than Soldiers who reportedly had worn occupant restraints during a HMMWV rollover accident. Wearing occupant restraints could have saved 69 percent of Soldiers' lives lost from being unrestrained in HMMWV rollover accidents and 41 percent of all Soldiers' lives lost in HMMWV rollover accidents during the time period studied, reducing total fatality costs by 59 percent ($3.8 to $12.7 million). These findings support the use of occupant restraints as a life-saving, injury-mitigating and cost-saving countermeasure in HMMWV rollover accidents. More command and peer-to-peer enforcement of mandatory restraint use in HMMWVs and other tactical vehicles used in Army operations is necessary.

15. SUBJECT TERMS

High mobility multipurpose wheeled vehicles, HMMWV rollover accidents, HMMWV rollover accident prevention, HMMWV rollover injuries, HMMWV rollover injury prevention

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Loraine St. Onge, Ph.D.
UNCLAS	UNCLAS	UNCLAS	SAR	24	19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

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Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Preface

This research conducted on occupant injuries in U.S. Army High Mobility Multipurpose Wheeled Vehicle (HMMWV) rollover accidents was presented at the 11th Annual Force Health Protection Conference in Albuquerque, New Mexico, August 2008. The poster, entitled "Prevention of Injury in Tactical Vehicle Rollover Accidents–HMMWV," was awarded best research presentation out of 68 entries at the conference. Contributors to this effort were Robert Giffin, M.S.O.H., Kraig Pakulski, M.S., Paul St. Onge, Ph.D., Parrish Balcena, M.D., M.P.H., Joseph McEntire, M.S., and LTC Shean Phelps, M.D., M.P.H.

Table of contents

Table of contents (continued)

List of figures

List of tables

Introduction

The High Mobility Multipurpose Wheeled Vehicle (HMMWV) is a light tactical vehicle designed to transport personnel and light cargo (Federation of American Scientists Military Analysis Network, 2000). Reinforced armor plating systems were added onto the HMMWV, which was not originally designed to accept such improvements (Carollo & Wagner, 2006). While reducing the probability of platform penetration and increasing occupant survivability, these heavy up-armor kits alter the HMMWV's center of gravity, destabilizing the vehicle and making it more difficult to control and more likely to roll over, especially in harsh conditions (Carollo & Wagner, 2006).

In the event of a rollover or multiple rollovers, a HMMWV rotates 90 degrees or more, resulting in the vehicle landing on its side or roof, as shown in appendix A. Soldiers strapped in their seats may be flipped numerous times, and possibly left hanging upside down. Unrestrained Soldiers may experience the full impact of jarring forces and/or projectile forces of unrestrained equipment. Rollovers are especially hazardous to turret gunners (TGs) who are often unable to retract themselves quickly enough into the vehicle, and are either ejected or pinned under the overturned vehicle (Pickerell, 2006).

Lack of restraint use and rollovers have been identified as two separate, independent factors causing the most severe injuries or fatalities in HMMWV accidents (Pennsylvania Department of Military and Veterans Affairs [PDMVA], 2005). Safety belt/restraint use is the single most effective countermeasure to prevent occupant deaths and injuries and reduce the costs associated with civilian motor vehicle accidents (National Highway Traffic Safety Administration [NHTSA], 2003). Most drivers recognize safety belts are effective in reducing or preventing motor vehicle crash injuries, but many do not use them. This is particularly true of young males who make up the majority of military personnel (Hagenzeiker, 1991). All U.S. Army personnel, except those providing emergency medical care, are required by Department of the Army (DA) Regulation 385-10 (DA, 2011), to wear installed occupant restraint devices while operating or riding a motor vehicle to comply with the Army's motor-vehicle accident prevention policy (DA, 2011). Even with these regulations in place, Soldiers are often reluctant to use seat belts, concerned seat belts will impede their egress in a firefight or improvised explosive device (IED) explosion (Wood, 2008). Members of the 16th Military Police Brigade experienced the importance of seat belt use first-hand after surviving a HMMWV IED explosion and subsequent triple rollover during a patrol in Baghdad in 2006 (Robson, 2006). Soldiers using seat belts remained in the vehicle during the rollover and were not seriously injured. The driver, who was not wearing a seat belt, was thrown out of the vehicle and received injuries, including a concussion with loss of consciousness, and a laceration requiring 10 stitches. Although this was a combat event and not an accident, this particular incident illustrates the difference seat belt use can make during a rollover.

To date, relatively few studies have been conducted on U.S. Army ground vehicle rollovers and injuries to Soldiers. An analysis of Army Safety Management Information System (ASMIS) data conducted by the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), now renamed the U.S. Army Public Health Command, found 42 percent of all Soldiers injured in HMMWV accidents in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) during calendar years 2003 and 2004 were injured in a rollover

accident (Canham-Chervak, Canada, Hauret, Hadley, & Jones, 2005). The analysis also found more than 26 percent of injuries caused by military vehicle rollover accidents were fatal, and Soldiers who did not wear seat belts were three times more likely to die in a rollover accident than Soldiers who did wear seat belts. Additional epidemiological studies are needed to describe the incidence, type, severity, and risk factors for these injuries (Krahl, Jankosky, Thomas, & Hooper, 2010).

In response to this need, the Operational Survival Analysis Section (OSAS), an interdisciplinary team funded by the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) Program to provide contract support to the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, analyzed ASMIS data to describe fatalities and injuries associated with HMMWV rollover accidents. The objectives of this study were to: (1) describe the demographics of occupants involved in U.S. Army HMMWV rollover accidents and the severity of such accidents using the Department of Defense (DOD) accident classification (DOD, 2008), (2) determine the effect of restraint use on the severity of injuries sustained by occupants involved in such accidents, and (3) calculate the economic costs of these accidents. Findings from this study are expected to help fill the knowledge gap Krahl et al. (2010) identified, and highlight the need to enforce mandatory occupant restraint use as an effective countermeasure to prevent or mitigate occupant injuries.

Methods

Data source and study design

The data analyzed in this study was gathered from the ASMIS, a data base of U.S. Army accident reports required by DA Regulation 385-10, The Army Safety Program (DA, 2011), to be reported to the U.S. Army Combat Readiness / Safety Center (USACR / SC). The accident report captures circumstantial information on the accident (including accident classification), personnel involved, property or materiel involved, and environmental conditions involved. The accident report also documents a narrative description of the accident, corrective action recommended, and a review of the accident report by commanding officers.

HMMWV rollover accidents meeting the inclusion criteria (table 1) were identified. Using a retrospective cohort study design, *exposed* individuals were defined as personnel who did not wear occupant restraints and *unexposed* individuals were defined as personnel who did wear occupant restraints. This study design enabled the relative risk of fatalities to be calculated.

Table 1.
Study parameters.

Study design	Retrospective cohort study.
Population	Soldiers and civilians involved in HMMWV rollovers.
Dates	July 1989 to October 2007.
Data source	USACR / SC.
Vehicle platform	HMMWV.
Incident type	Accidents only.
Accident type	Overturned/rollover.
Distribution	Worldwide.
Inclusion criteria	HMMWV rollover. Restraints reported as present in vehicle. Restraint use reported as *yes, no,* or *blank.*

Data analysis

Analyses were conducted on personnel who were HMMWV occupants involved in non-stationary rollover accidents. Age, gender, enlistment status, and rank were analyzed to describe occupant demographics. Reported restraint use was identified by the following fields in the ASMIS data base (field values are indicated in parentheses): *Type of Protective Equipment* (*seatbelt*), *Protective Equipment Available* (*yes*), and *Protective Equipment Used* (*yes, no,* or *blank*). These fields and field values were analyzed to describe the reported use of occupant restraints. Frequency of HMMWV rollover accidents in each accident classification, categorized according to the materiel damage cost and injury severity thresholds listed in table 2 (DOD, 2008) in effect at the time of the HMMWV rollover accidents included in this study, was noted along with the reported use or non-use of occupant restraints. The frequency of each injury outcome in table 2 was also noted along with the reported use or non-use of occupant restraints.

Table 2.
DOD accident classification.

Classification	Property damage	Injury outcome
A	An Army accident in which the resulting total cost of property damage is $1,000,000 or more.	An injury and/or occupational illness resulting in a fatality or permanent total disability.[1]
B	An Army accident in which the resulting total cost of property damage is $200,000 or more, but less than $1,000,000.	An injury and/or occupational illness resulting in permanent partial disability,[2] or when three or more personnel are hospitalized as inpatients as the result of a single occurrence.
C	An Army accident in which the resulting total cost of property damage is $20,000 or more, but less than $200,000.	A non-fatal injury causing any loss of time from work beyond the day or shift on which it occurred; or a non-fatal occupational illness causing loss of time from work (for example, one work day) or disability at any time (lost time case).
D	An Army accident in which the resulting total cost of property damage is $2000 or more, but less than $20,000.	Non-fatal injuries/illnesses (restricted work activity: light duty profile) will only be recorded in ASMIS in conjunction with recordable property damage accidents.

Note: The cost thresholds specified in this table were in effect at the time of the HMMWV rollover accidents included in this study. These cost thresholds were increased in the 25 February 2010 rapid action revision of DA Pamphlet 385-40, Army Accident Investigations and Reporting (DA, 2010). The property value of a HMMWV is less than $100,000.

[1]Person can never do gainful work.

[2]Person loses or can never use a body part.

Damage and injury costs were assessed for each accident by the accident investigator. Injury costs were determined based on the injury outcome documented in the accident report, according to a table of standard costs for each injury outcome in table 2 developed by the DOD for accident reporting purposes (DOD, 2008; DA, 2010). Total accident costs, including damage and injury costs, were summed for each accident classification.

Fatality costs were extrapolated from injury costs. A range of fatality costs was calculated. The upper limit of this range was obtained by summing the injury costs of all class A (fatal) HMMWV rollover accidents during the time period of this study. To determine the lower limit of this range, weighted fatality costs for each fiscal year (FY) were calculated by dividing the number of fatalities by the total number of fatally and non-fatally injured personnel for each FY, then multiplying by the total injury cost for that FY. These weighted fatality costs were then summed to obtain the lower limit of this range. Upper and lower cost limits per fatality were obtained by dividing the upper and lower fatality cost limits, respectively, by the total number of fatalities.

Risk determination

Several measures of relative risk (Friedman, 1994) were calculated to compare the risk of HMMWV rollover accident fatalities of exposed vs. unexposed personnel. A risk ratio (RR) was calculated to determine the relative risk of HMMWV rollover accident fatalities when occupant restraints were reportedly not used (exposed), compared to when they were reportedly used (unexposed). The excess fatalities attributable to the reported lack of restraint use among exposed personnel relative to unexposed personnel were determined by calculating the attributable risk percent (ARP). The excess fatalities attributable to the reported lack of restraint use among exposed personnel relative to the entire study population of exposed and unexposed personnel were determined by calculating the population attributable risk percent (PARP).

Results

Summary statistics

A total of 454 HMMWV rollover accidents meeting the inclusion criteria were identified and broken down as follows: class A (93 accidents), class B (34 accidents), class C (264 accidents), and class D (63 accidents). A total of 789 personnel were injured in these accidents, sustaining 1167 fatal and non-fatal injuries (an individual could have sustained more than one injury). Table 3 shows demographics for the 789 injured personnel who had a mean age of 25.2 years. Of the injured personnel, 84 percent were male and 88 percent were enlisted Soldiers. Approximately 42 percent were drivers of and 51 percent were passengers in the HMMWV involved in a rollover accident.

Table 3.
Subject demographics.

Demographic	*n*	%
Age (years)		
Mean	25.2	-
Range	14-61	-
Sex		
Male	661	83.8
Female	64	8.1
Unreported	64	8.1
Rank		
Officers	30	3.8
Enlisted	693	87.8
Unreported	66	8.4
Vehicle occupants		
Drivers	332	42.1
Passengers	402	51.0
Unreported	55	7.0

Reported restraint use

Figure 1 shows percentages of U.S. Army HMMWV occupants reportedly using restraints at the time of a rollover accident by accident classification. Reported restraint use increased with each successively less severe accident classification, from a low of 44 percent in class A to a high of 91 percent in class D. Although reported restraint use appeared to mitigate accident severity, no cause-effect relationship can be implied due to possible reporting bias. For example, restraint use could have been more likely reported for occupants who were not ejected than for occupants who were ejected and died. Restrained occupants could also have been ejected due to forces exceeding design criteria, further confounding the relationship between reported restraint use and accident severity.

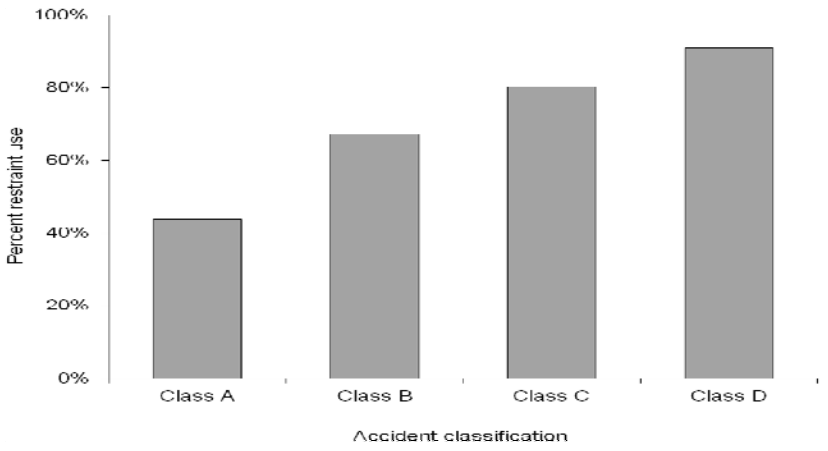

Figure 1. Percent reported restraint use by accident classification.

Severity and frequency of injuries sustained by accident classification

Table 4 compares by accident classification and reported restraint use, injury severity outcomes of Soldiers involved in 1989 to 2007 HMMWV rollover accidents. Fifty-six (7 percent) of the 789 injured personnel were excluded from this table because of an ASMIS data base entry error, whereby restraints were not noted to be present in the vehicle, leaving the data of 733 personnel for analysis.

Table 4.
Soldier injuries and percent reported restraint use for each accident classification.

	Soldier injuries and reported restraint use (%)											
	Class A *n* = 216			Class B *n* = 97			Class C *n* = 341			Class D *n* = 79		
Injury outcome	Yes	No	NR	Yes	No	NR	Yes	No	NR	Yes	No	NR
Fatal	*n* = 100											
	35	50	15									
Disability	*n* = 7			*n* = 18								
	57	29	14	28	33	39						
Lost work day	*n* = 65			*n* = 62			*n* = 236					
	37	57	6	68	24	8	73	21	6			
Restricted work	*n* = 9			*n* = 4			*n* = 25			*n* = 21		
	33	67	0	50	50	0	72	28	0	90	5	5
First aid	*n* = 35			*n* = 13			*n* = 80			*n* = 58		
	51	37	11	62	38	0	86	10	4	86	10	3

Note: NR = not reported.

Intra-class comparisons of injury outcomes by reported restraint use showed some evidence that reported restraint non-use was associated with a more severe injury outcome, but this was not always consistent. For example, within class A accidents, 50 percent of Soldiers who died reportedly did not use restraints at the time of the HMMWV rollover accident, while only 29 percent of Soldiers who sustained a disability and 37 percent of Soldiers who required only first aid reportedly did not use restraints at the time of the accident. (It is recognized, however, that reporting bias could exist here, whereby restraint non-use is more likely to be reported for occupants who died, than for those who did not die.) Likewise, within class C accidents (the largest accident classification in this study), 21 percent of Soldiers who lost a work day and 28 percent of Soldiers who were put on restricted work reportedly did not use restraints at the time of the HMMWV rollover accident, whereas 10 percent of Soldiers who required only first aid reportedly did not use restraints at the time of the accident. However, within class A accidents, a

greater percentage of Soldiers who lost a work day or were put on restricted work (57 percent and 67 percent, respectively) reportedly did not use restraints at the time of the accident, compared to the percentage of Soldiers who died and reportedly did not use restraints (50 percent).

Within class D accidents, only 5 percent of Soldiers who were put on restricted work and 10 percent of Soldiers who required only first aid reportedly did not use restraints at the time of the HMMWV rollover accident. This suggests a general trend that reported restraint use protected against more severe injuries during a HMMWV rollover accident, both within and across accident classifications.

Figures 2 and 3 separate and compare by reported restraint use, the injury severity outcomes of Soldiers injured in 1989 to 2007 class A HMMWV rollover accidents, and 1989 to 2007 class B through class D HMMWV rollover accidents, respectively. Compared to figure 2, the higher percentages of reported restraint use in the less severe accident classifications and in each injury outcome category in figure 3, in particular the "lost work day," "restricted work," and "first aid" injury severity outcomes, were evident in these graphical depictions of the data, which highlight the reported restraint use disparity between those injured in catastrophic accidents (figure 2) and less severe accidents (figure 3).

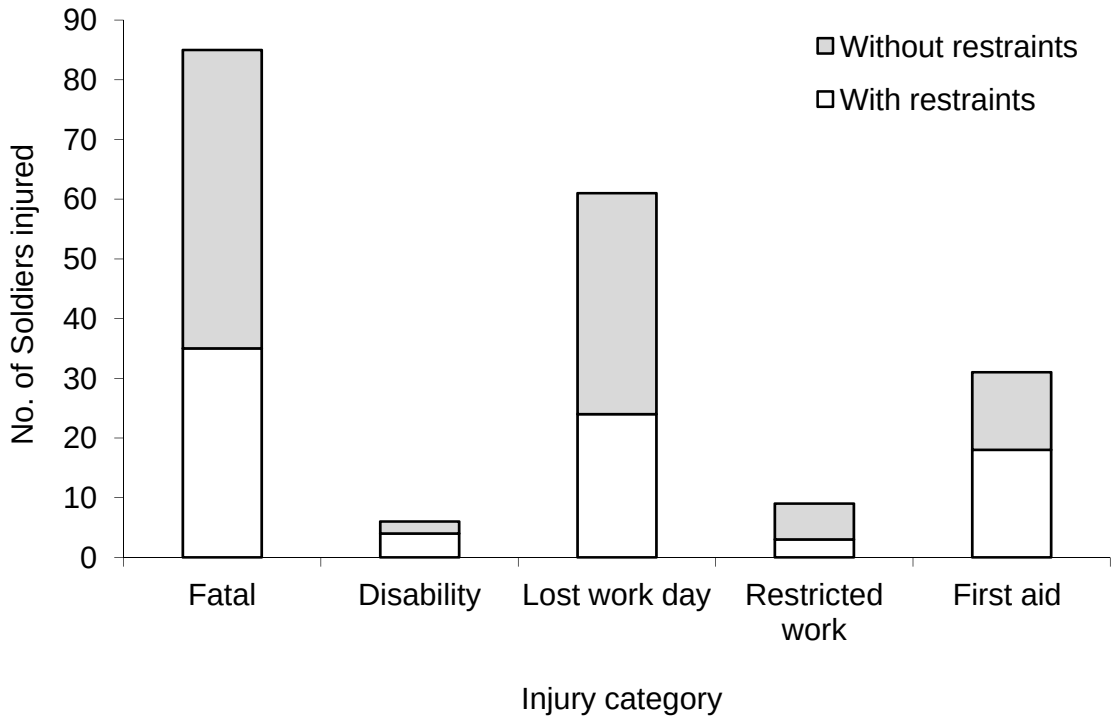

Figure 2. Soldiers injured in class A rollovers.

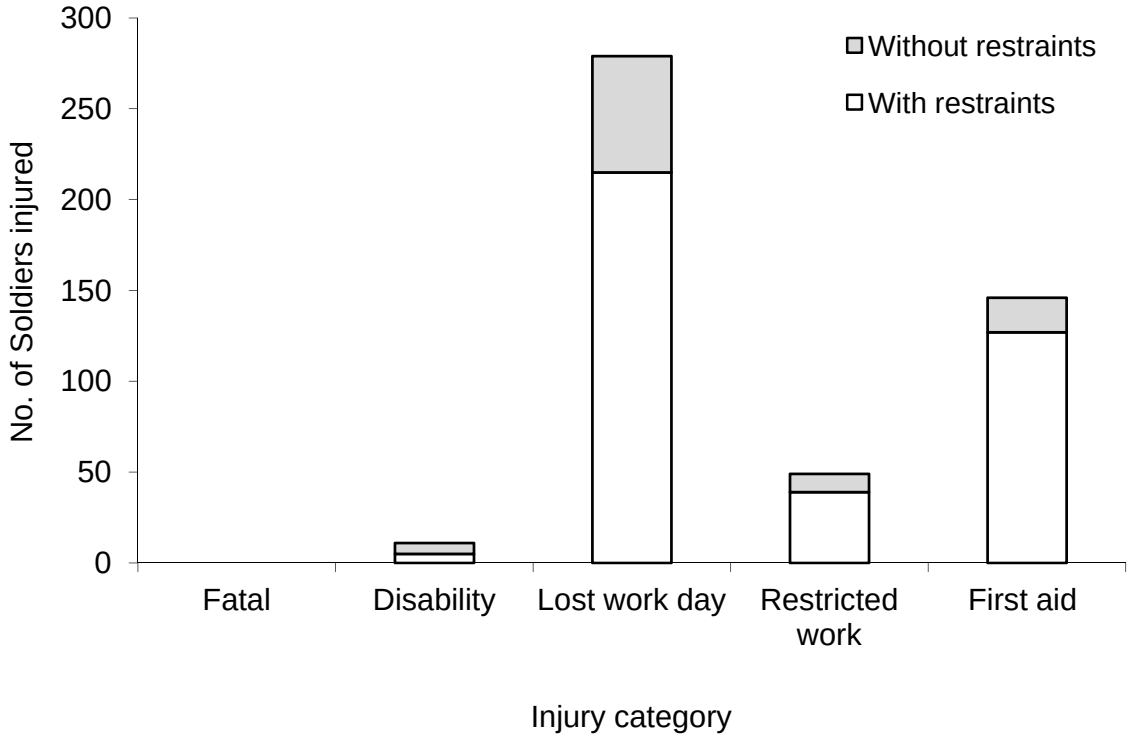

Figure 3. Soldiers injured in class B through D rollovers.

Accident cost analyses

Figure 4 separates by personnel injury and materiel damage costs for each accident classification, 1989 to 2007 U.S. Army HMMWV rollover accident costs. Personnel injury costs predominated, accounting for more than one-half (59 percent) of total accident costs, with 46 percent resulting from class A accidents alone. Total class A accident costs (approximately $24.8 million), were more than the total accident costs for class B through class D accidents combined (approximately $21.0 million). Materiel damage costs increased with each successively less severe accident classification, except for class D accidents, which cost the least of all accident classifications (approximately $1.3 million). Materiel damage costs equaled two-thirds of total class B accident costs and three-fourths of total class C accident costs. The reverse was true of total class A accident costs, of which personnel injury costs equaled 86 percent. No injury costs were incurred in class D HMMWV rollover accidents.

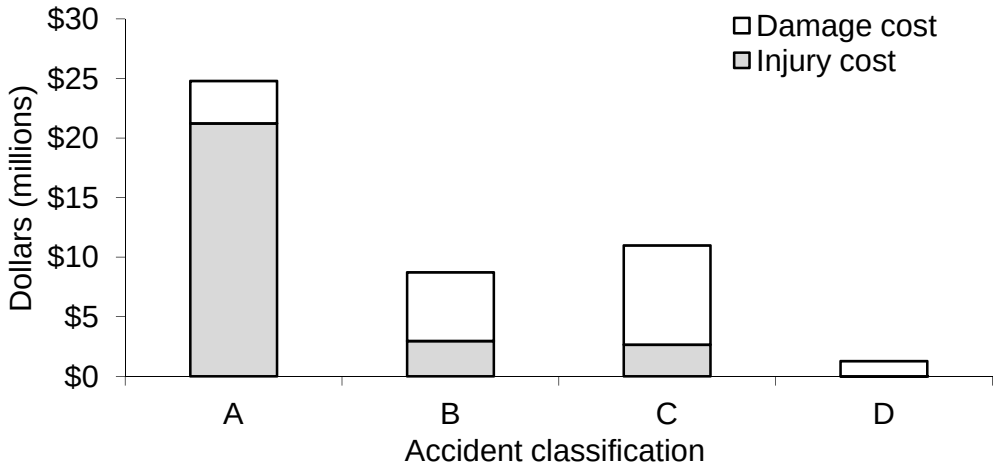

Figure 4. HMMWV rollover costs by accident classification.

Figure 5 separates by FY from 1989 through 2006, U.S. Army HMMWV rollover accident costs, fatalities, and non-fatal injuries. Fatalities, non-fatal injuries, and their associated costs due to HMMWV rollover accidents began to rise sharply in FY 2002 and peaked in FY 2005, coinciding with the Army's combat operations in Iraq and Afghanistan.

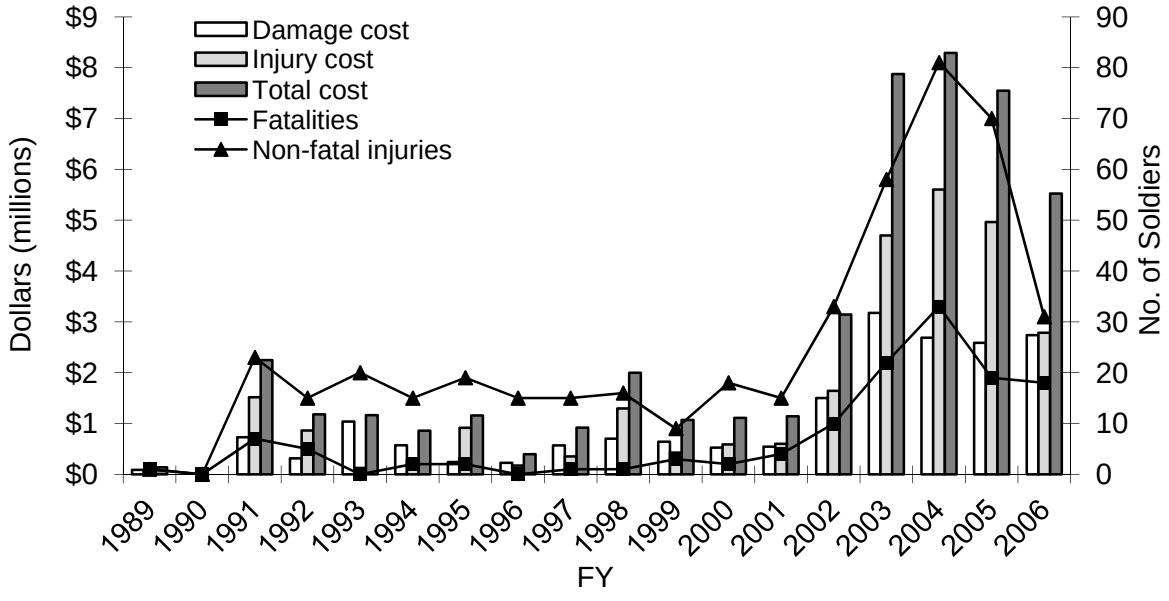

Figure 5. Costs of HMMWV rollovers by FY.

Table 5 shows the cost of 1989 through 2007 U.S. Army HMMWV rollover accident fatalities and potential cost reductions if all occupants had used restraints. Universal restraint use at the time of a HMMWV rollover accident could have potentially reduced total fatality costs by as much as 59 percent, or $12.7 million, based on the upper limit of fatality costs calculated as described above. This assumes all fatalities in which restraints had not been used were, in fact, attributable to the lack of restraint use. Because this assumption might not always be correct for every unrestrained fatality, these cost reductions therefore represent the maximum estimated cost savings that potentially could have resulted from universal restraint use.

Table 5.
Cost of fatalities and cost reductions with increased restraint use.

	Total fatalities (n = 85)		Fatalities when using restraints (n = 35)		
Cost limit	Total costs	Cost per fatality	Total costs	Cost reduction	Percent reduction
Upper	$21,349,344	$251,169	$8,690,439	-$12,658,905	-59.3
Lower	$6,483,788	$76,280	$2,639,283	-$3,844,505	-59.3

Calculations of relative risk

Table 6 shows fatality incidence by reported restraint use of occupants involved in 1989 to 2007 U.S. Army HMMWV rollover accidents. Based on the table data, an RR was calculated to determine the relative risk of fatalities of personnel who reportedly did not use restraints compared to personnel who reportedly used restraints. That RR is 3.2, calculated as follows: [50/207] / [35/470] = 3.2 (95 percent confidence interval 2.2 to 4.8), as referenced in table 7.

Table 6.
Incidence values used for determining RR and risk calculations.

Reported restraint use	Fatal	Non-fatal	Total
No	50	157	207
Yes	35	435	470
Total	85	592	677

Table 7 shows 1989 to 2007 U.S. Army HMMWV rollover fatality rates per year per 1000 accidents. These rates were calculated for unrestrained personnel ([{50/207} x 1000] / 17 = 14.2) and restrained personnel ([{35/470} x 1000] / 17 = 4.4). The difference was 9.8, which was the excess risk of fatalities among unrestrained personnel attributable to the reported lack of restraint use during a HMMWV rollover accident (attributable risk [AR]). This difference was 69 percent of the fatality rate of restrained personnel ([9.8/14.2] x 100 = 69.2 percent), meaning 69 percent of fatalities among unrestrained personnel was attributable to the reported lack of restraint use during a HMMWV rollover accident (attributable risk percent [ARP]).

Table 7.
Calculations associated with not using restraints.

Measure	Value	Interpretation
Fatality rate (unrestrained)	14.2	Rate of HMMWV rollover fatalities without reported restraint use / year / 1000 accidents.
Fatality rate (restrained)	4.4	Rate of HMMWV rollover fatalities with reported restraint use / year / 1000 accidents.
Fatality rate (study population)	7.4	Rate of HMMWV rollover fatalities with and without reported restraint use / year / 1000 accidents.
RR	3.2	Risk of fatality if restraints are reportedly not used.
AR	9.8	Rate of excess fatalities among unrestrained personnel attributable to reported lack of restraint use.
ARP	69.2%	Percentage of fatalities among unrestrained personnel attributable to reported lack of restraint use.
PAR	3.0	Rate of excess fatalities in the study population attributable to reported lack of restraint use.
PARP	40.7%	Percentage of fatalities in the study population attributable to reported lack of restraint use.

Note: RR = risk ratio; AR = attributable risk; ARP = attributable risk percent; PAR = population attributable risk; PARP = population attributable risk percent.

The rate of HMMWV rollover fatalities per year per 1000 accidents was also calculated for the entire study population of unrestrained and restrained personnel ([{85/677} x 1000] / 17 = 7.4). Compared to the fatality rate of restrained personnel (4.4), the difference was 3.0, which

was the rate of excess fatalities in the entire study population attributable to the reported lack of restraint use during a HMMWV rollover accident (PAR). This difference was 41 percent of the fatality rate of the entire study population ([3.0/7.4] x 100 = 40.7 percent), meaning 41 percent of fatalities in the entire study population were attributable to the reported lack of restraint use during a HMMWV rollover accident (PARP).

Discussion

The study results showed HMMWV rollover accidents result in severe injuries and fatalities when restraints were not used, confirming previous findings (PDMVA, 2005). Soldiers who reportedly had not worn restraints were three times more likely to die during a HMMWV rollover accident than Soldiers who reportedly had worn restraints. Wearing restraints could have saved 69 percent of Soldiers' lives, which were lost from reportedly being unrestrained in HMMWV rollover accidents, and 59 percent ($3.8 to $12.7 million) in associated fatality costs during the time period studied (1989 through 2007). Furthermore, wearing restraints could have saved 41 percent of all Soldiers' lives lost in HMMWV rollover accidents during this time period. These findings support the effectiveness of occupant restraints as a life-saving, injury-mitigating, and cost-saving countermeasure in HMMWV rollover accidents, consistent with findings from civilian motor vehicle accidents (NHTSA, 2003). However, this study did not look at reported problems with restraint use, such as entrapment resulting in delayed egress during an emergency, which could decrease the benefit of restraint use or number of lives saved.

Recommendations to increase and sustain restraint use by civilians in privately-owned vehicles (POVs), such as increased educational efforts, incentive programming, and enhanced enforcement with high visibility and publicity (NHTSA, 2003), may be effective in increasing and sustaining restraint use by Soldiers in Army ground vehicles. These initiatives may reduce or prevent fatalities and serious injuries in a rollover or other accident. A campaign combining enforcement with incentives was found to be effective in increasing and sustaining occupant restraint use three months post-campaign among Dutch military personnel (Hagenzeiker, 1991).

The Deployment and Operations Task Force (DOTF), Joint Staff J-39 Readiness Division, has outlined an approach to reduce or prevent accidents among deployed military personnel, including proactive efforts to collect accident data, disseminate safety lessons learned, and share information to reduce or prevent accidents during force deployments and operations (VanderHamm, Rice, Chervak, & Giffin, 2010). This approach emphasizes awareness advocacy at all levels of leadership, combined with support of and a commitment to safety issues and initiatives. The USACR / SC has implemented similar initiatives for Army personnel, in addition to its safety mandates (DA, 2011).

The Army reported making positive strides in reducing class A accidents and fatalities during FY 2008 (Thompson, Lyle, & Davis, 2009), which was the year after the final year covered by this study. Accidents involving Army vehicles decreased, but class A accidents involving Soldiers in POVs continued to be a problem. The reported lack of restraint and other PPE use was found to have contributed to these fatalities. In this study of Army HMMWV rollover accidents and occupant injuries over a 17-year period, the benefits of reported restraint use in conserving the health and safety of Army Warfighters involved in such accidents were found to

be substantial, potentially reducing the overall number of fatalities by 41 percent, and associated costs by up to 59 percent (as much as $12.7 million).

Limitations

Several limitations were inherent in the study data, which were abstracted from the ASMIS administrative data base of accident reports filed with the USACR / SC. These accident reports did not capture physical injuries in sufficient clinical detail to describe specific causes of injury morbidity and mortality in HMMWV rollover accidents. Therefore, this study assumed the cause of death in class A HMMWV rollover accidents was primarily because of blunt trauma and/or flail injury, and the findings and interpretations given were based on an upper estimate of fatality costs. Linkages to clinical data bases capturing these fatalities may provide details needed to describe these injuries more fully.

Restraint use was unreported for 112 (14 percent) of the 789 Soldiers in this study injured in HMMWV rollover accidents (table 3), reflecting a possible reporting bias. The impact of missing data on the study results was unknown. Restraint non-use may be under-reported because of perceived consequences of noncompliance with the Army's restraint-use requirement in motor vehicles (DA, 2011). Alternatively, there could have been more over-reporting of restraint use in less severe accidents than in accidents involving serious injury or fatality. Nevertheless, more complete reporting of restraint use would have minimized any bias introduced into the study results as a consequence of missing data.

Conclusions

Analysis of available HMMWV rollover accident data reported to the USACR / SC during the time period studied (1989 through 2007) supports occupant restraint use as critical to reducing Soldier fatalities, and by extension, HMMWV rollover accidents categorized as class A accidents because of these fatalities. Soldiers who reportedly did not wear restraints were three times more likely to die than Soldiers who reportedly wore restraints during a HMMWV rollover accident. Approximately 69 percent of Soldier fatalities (out of those reportedly not wearing restraints) could have been prevented by restraint use. Approximately 41 percent of all Soldier fatalities (1989 through 2007) involved in a HMMWV rollover accident could have been prevented with restraint use.

To leverage the life-saving and injury-mitigating protection that restraint use confers to HMMWV occupants in a rollover accident, this study suggests the substantial safety benefits of restraint use should be emphasized during the training and practice drills Soldiers receive on HMMWV rollover procedures (Pickerell, 2006). Leaders and peers should actively encourage and model restraint use as an effective countermeasure to manage and contain fatality risk and severe injuries HMMWV rollover accidents pose to Soldiers, monitoring and enforcing compliance with this mandatory safety practice when necessary. Implementation of these measures may save Soldiers' lives, lessen injury severity, and mitigate fatality and injury costs substantially.

Recommendations

This study's findings support the use of occupant restraints as a life-saving and injury-mitigating countermeasure in HMMWV rollover accidents. Therefore, restraint use should be advocated and enforced consistently in Army ground operations and training involving HMMWVs and other tactical vehicles equipped with occupant restraints (DA, 2011). Specific recommendations to leverage these findings into positive action include the following:

a. Engage safety officers Army-wide in enhanced outreach to educate Soldiers during safety briefings, emphasizing safety benefits of restraint use and the consequences of non-use.

b. Enforce mandatory restraint use by making Soldiers more accountable to each other during training and operations.

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Appendix A.

HMMWV rollover accidents.

Figure A1. Partial rollover. (U.S. Army photo)

Figure A2. Full rollover. (U.S. Army photo)

Prevention of Injury in Tactical Vehicle Rollover Accidents – HMMWV

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Introduction

The High Mobility Multipurpose Wheeled Vehicle (HMMWV) is a light tactical vehicle designed to transport personnel and light cargo. Reinforced armor plating systems had been added onto the HMMWV, which was not originally designed to accept such improvements. While reducing the probability of platform penetration and increasing occupant survivability, these heavy up-armor kits alter the vehicle's center of gravity and increase rollover risk.

Unpublished research by McEntire *et al.* found Soldiers perceive restraint use in the HMMWV restricts their ability to respond immediately during combat situations and/or emergency egress. Restraints were reported to hinder performance of mission duties, were incompatible with gear, and were difficult to don and doff. Soldiers carried these perceptions into non-combat/non-emergent situations, resulting in lower restraint use overall.

The Operational Survival Analysis Section (OSAS), U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, analyzed U.S. Army ground vehicle accident data, focusing on the incidence of injuries and fatalities resulting from HMMWV rollovers and the risk of fatality if restraints are not used. This poster provides an epidemiological overview of the injury data and a starting point for discussion of preventive and occupational modalities to mitigate these injuries.

Methods

Table 1. Study parameters.

Study design:	**Retrospective cohort study.**
Population:	**Soldiers and civilians involved in HMMWV rollovers.**
Dates:	**July 1989 to October 2007.**
Data source:	**U.S. Army Combat Readiness/Safety Center (USACRSC).**
Vehicle platform:	**HMMWV.**
Incident type:	**Accidents only.**
Accident type:	**Overturned/rollover.**
Distribution:	**Worldwide.**
Inclusion criteria:	**HMMWV rollover.**
	Restraints reported as present in vehicle.
	Restraint use reported as *yes*, *no*, or *unclear*.

Table 2. Army accident classification.

Classification	Property Damage	Injury Outcome
A	An Army accident in which the resulting total cost of property damage is $1,000,000 or more.	Injury and/or occupational illness resulting in a fatality or permanent total disability.
B	An Army accident in which the resulting total cost of property damage is $200,000 or more, but less than $1,000,000.	An injury and/or occupational illness resulting in permanent partial disability, or when three or more personnel are hospitalized as inpatients as the result of a single occurrence.
C	An Army accident in which the resulting total cost of property damage is $20,000 or more, but less than $200,000.	A nonfatal injury causing any loss of time from work beyond the day or shift on which it occurred, or a non-fatal occupational illness causing loss of time from work (for example, one work day) or disability at any time (lost time case).
D	An Army accident in which the resulting total cost of property damage is $2000 or more, but less than $20,000.	Non-fatal injuries/illnesses (restricted work activity, light duty profile) will only be recorded in ASMIS in conjunction with recordable property damage accidents.

Note: The property value of a HMMWV is less than $100,000. Class A and B accidents are classified on the basis of fatality or injury.

Two data fields were used to determine restraint use:

a. *PPE Description* listed all of the personal protective equipment (PPE) identified and cataloged in the HMMWV investigation, including restraint systems, seatbelts, and turret gunner straps.

b. *PPE Use Description* described PPE use/presence at the time of investigation (*yes*, *no*, or *unclear*).




Summary Statistics

- 454 HMMWV rollover accidents.
- 789 individuals injured.
  - 112 (14%) individuals were excluded due to unreported or unclear restraint use.
- 1167 injuries sustained.

Table 3. Subject demographics.

Demographic	Number	Percent
Age (years)		
Mean	25.2	-
Range	14-61	-
Sex		
Male	661	83.8%
Female	64	8.1%
Unreported	64	8.1%
Rank		
Officers	30	3.8%
Enlisted	693	87.8%
Unreported	66	8.4%
Vehicle occupants		
Drivers	332	42.1%
Passengers	402	51.0%
Unreported	55	7.0%

Table 4. Soldier injuries and percent restraint use for each accident classification.

Accident class / injury outcome	Class A		Class B		Class C		Class D	
	Number	Restraint use	Number	Restraint use	Number	Restraint use	Number	Restraint use
Fatal	100	Y=35% N=50% NR=15%						
Disability	7	Y=57% N=29% NR=14%	18	Y=28% N=33% NR=39%				
Lost workday	65	Y=37% N=57% NR=6%	62	Y=68% N=24% NR=8%	236	Y=73% N=21% NR=6%		
Restricted work	9	Y=33% N=67% NR=0%	4	Y=50% N=50% NR=0%	25	Y=72% N=28% NR=0%	21	Y=90% N=5% NR=5%
First aid	35	Y=51% N=37% NR=11%	13	Y=62% N=38% NR=0%	80	Y=86% N=10% NR=4%	58	Y=86% N=10% NR=3%
Total	216		97		341		79	

Note: Y = yes, N = no, NR = not reported.

Results

Figure 1. Percent restraint use by accident classification.

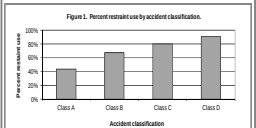


Figure 1 shows percent restraint use by accident classification. Restraint use increased with each successively less severe accident classification, from 44% in class A to 91% in class D.

This finding strongly suggests that as reported restraint use increased, the severity of injuries sustained in a HMMWV rollover accident decreased.

Figure 2. Soldiers injured in Class A rollovers.

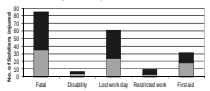
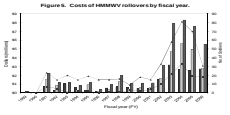


Figure 3. Soldiers injured in Class B-D rollovers.

Figures 2 and 3 compare the injury severity of Soldiers in class A accidents (figure 2) vs. class B-D accidents (figure 3) by restraint use. Together these figures highlight the restraint use disparity between those injured in catastrophic vs. less severe accidents.

Figure 4. HMMWV rollover costs by accident classification.

Figure 5. Costs of HMMWV rollovers by fiscal year.



Figures 4 and 5 highlight the economic impact of HMMWV rollovers by accident class and fiscal year (FY). Injury costs predominated, with almost half resulting from class A accidents alone. HMMWV rollover fatalities, non-fatal injuries, and resulting costs rose sharply in FY 2002 and peaked in FY 2005, coinciding with war operations in Iraq and Afghanistan.

Table 5. Cost of fatalities and cost reductions with increased restraint use.

Cost limit	Total fatality costs	Cost per fatality	Total fatality costs when using restraints	Cost reduction (percent)
Upper limit	$21,349,344	$251,169	$8,680,439	$12,668,905 (59%)
Lower limit	$6,483,788	$76,280	$2,639,283	$3,844,505 (59%)

Calculations of Relative Risk

Table 6. Incidence values used for determining risk ratio and risk calculations.

Restraint use	Fatal	Non-fatal	Total
No (exposed)	50	157	207
Yes (unexposed)	35	435	470
Total	85	592	677

Table 7. Calculations associated with not using restraints.

Measure	Value	Interpretation
Fatality rate (exposed personnel)	14.2	Rate of HMMWV rollover fatalities without restraint use / year / 1000 accidents.
Fatality rate (un-exposed personnel)	4.4	Rate of HMMWV rollover fatalities with restraint use / year / 1000 accidents.
Fatality rate (study population)	7.4	Rate of HMMWV rollover fatalities with and without restraint use / year / 1000 accidents.
Risk ratio	3.2	Risk of fatality if restraints are not used.
Attributable risk (AR)	9.8	Rate of excess fatalities among exposed personnel attributable to lack of restraint use.
Attributable risk percent (ARP)	69.2%	Percentage of fatalities among exposed personnel attributable to lack of restraint use.
Population attrib-utable risk (PAR)	3.0	Rate of excess fatalities in the study population attributable to lack of restraint use.
Population attrib-utable risk percent (PARP)	40.7%	Percentage of fatalities in the study population attributable to lack of restraint use.

Discussion

a. Soldiers who did not wear restraints were three times more likely to die in a HMMWV rollover accident than Soldiers who had worn restraints.

b. Wearing restraints could have saved **69%** of Soldier fatalities from being unrestrained in a HMMWV rollover, **41%** of all Soldier fatalities due to a HMMWV rollover, and **59%** in fatality costs due to a HMMWV rollover.

c. **Limitations:** This study did not look at problems with restraint use such as entrapment, which could delay egress during an emergency. These results are only as accurate as the data reported. 14% of individuals were excluded from this study due to unreported or unclear restraint use.

Conclusion

Restraint use confers life-saving and injury-mitigating protection to HMMWV occupants during a rollover accident.

Recommendations

a. Emphasize the safety benefits of restraint use and the consequences of non-use during safety briefings.

b. Enforce mandatory restraint use per Army Regulation 385-10 through command and peer-to-peer enforcement.

c. Conduct HMMWV Egress Assistance Trainer (HEAT) drills periodically.

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